Radio Telegraphy*

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During the first decade of its existence, the Proceedings *published a number of important papers by foremost pioneers of the infant radio engineering art which today are of major historical interest. Since less than one per cent of the present generation of IRE members were* Proceedings *readers at that time, it is planned to republish a few of these early papers during the coming months in commemoration of IRE's Golden Anniversary year.*

The following paper is the first of the series. It was first presented before a joint meeting of the IRE and the American Institute of Electrical Engineers on June 20, 1922, on the occasion when the IRE presented Marconi with the Medal of Honor. His response, which included a live demonstration, added a memorable and historically important chapter to the extension of the radio art into the UHF region of the spectrum.—The Editor

THE FIRST OCCASION on which I had the honor of speaking before the members of the American Institute of Electrical Engineers was of a very festive nature.

It is over twenty years ago, to be exact on January 13, 1902; (there was not then any Radio Institute in existence) and on that date, memorable for me, I was entertained by over 300 members of your Institute at a dinner at the Waldorf-Astoria in this City. I was offered that dinner following my announcement of the fact that I had succeeded in getting the first radio signal across the Atlantic Ocean.

Many men, whose names are household words in electrical science, were present, men such as Dr. Alexander Graham Bell, Professor Elihu Thompson, Dr. Steinmetz, Dr. Pupin, Mr. Frank Sprague, and many others.

The function was one I shall never forget, and displayed to the full American resource and originality, as only forty-eight hours' notice of the dinner had been given, but what has left the greatest impression on my mind during all the long twenty years that have passed is the fact that you believed in me and in what I told you about having got the simple letter "S" for the first time across the ocean from England to Newfoundland without the aid of cables or conductors.

It gives me now the greatest possible satisfaction to say that, in some measure, perhaps, your confidence in my statement was not misplaced, for those first feeble signals which I received at St. John's, Newfoundland, on the 12th of December, 1901, had proved once and for all that electric waves could be transmitted and received across the ocean, and that long-distance radiotelegraphy, about which so many doubts were then entertained, was really going to become an established fact.

You will easily understand my feelings and how very happy I am to have the honor of addressing you again tonight, and when I say that I will always treasure the recollection of the generous encouragement and valid support so heartily extended to me practically at the commencement of my career, when perhaps I most needed it, by such a distinguished and authoritative body as the American Institute of Electrical Engineers.

The subject of my lecture, "Radiotelegraphy," has become so vast and so complex that you will readily understand my difficulty as to where I shall begin and as to when I ought to stop. It would be quite impossible for me to descant at any length on present achievements in a country which in a very short time has made gigantic strides in the scientific development and practical application of the science and art of radiotelegraphy. Moreover, time will not allow me to do more than skim over only a very few of the many problems which have lately been solved, or which there is a good prospect of solving in the near future.

Although we have, or believe we have, all the necessary data for the generation, transmission, and reception of electrical waves, as at present utilized for radiotelegraphy, we are still far from possessing exact knowledge concerning the conditions governing the transmission, or rather the propagation, of these waves through

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space, especially across long distances.

I propose now to bring to your notice some of the recent results attained in Europe and elsewhere and to call your attention particularly to what I consider a somewhat neglected branch of the art; and which is the study of the characteristics and properties of very short electrical waves. My belief is always that, only by the careful study and analysis of the greatest possible number of well-authenticated facts and results, will it be possible to overcome the difficulties that still lie in the way of the practical application of radio in the broadest possible sense.

A very great impulse has been given to radiotelegraphy and telephony by the discovery and utilization of the oscillating electron tube or triode valve based on the observations and discoveries of Edision and Fleming, of those of De Forest and of those of Meissner in Germany, Langmuir and Armstrong in America, and H. W. Round in England, who have also brought it to a practical form as a most reliable generator of continuous electric waves.

As the electron tube, or triode valve, or valve, as it is now generally called in England, is able, not only to act as a detector, but also to generate oscillations, it has supplied us with an arrangement which is fundamentally similar for both transmitter and receiver, providing us also by a simple and practical method with the means for obtaining beat reception and an almost unlimited magnification of the strength of signals.

A result of the introduction of the triode valve has been that the basic inventions which made long-distance radiotelegraphy possible have become more and more valuable.

It may perhaps be of interest if I give some information as to the progress made by the Marconi Company in England, with the practical application of the triode valve.

It has been so far our practice to use a plurality of tubes in parallel at our long distance stations. High power has been obtained in practice up to 100 kilowatts in the antenna by means of a number of glass tubes in parallel, and for the present we are standardizing units capable of supplying 4 kilowatts to the antenna, in the numbers required and sufficient for each particular case.

Some difficulty was at first experienced in paralleling large tubes in considerable numbers, but no difficulties now occur with groups of 60 bulbs working on voltages of 12,000 on the plate.

I am told that no insurmountable difficulty would be encountered if it were desired to supply 500 kilowatts to the antenna from a number of these bulbs (Fig. 1). The life of the bulbs has been very materially increased and the 4-kilowatt units are expected to have a life, which, based on a great number of tests carried out both in the laboratory and at our Clifden station, should be well in excess of 5000 hours.

The development of single unit tubes of considerable power is also progressing. We have lately concentrated on the production of high power tubes made of quartz, and two sizes of each bulb are now being made, one for 25 kilowatts to the antenna, and another for 75 kilowatts, but it is not expected that the efficiency of the high power single units will be as good as that of the multiple units, and the work on the large tubes is being considered so far as experimental.

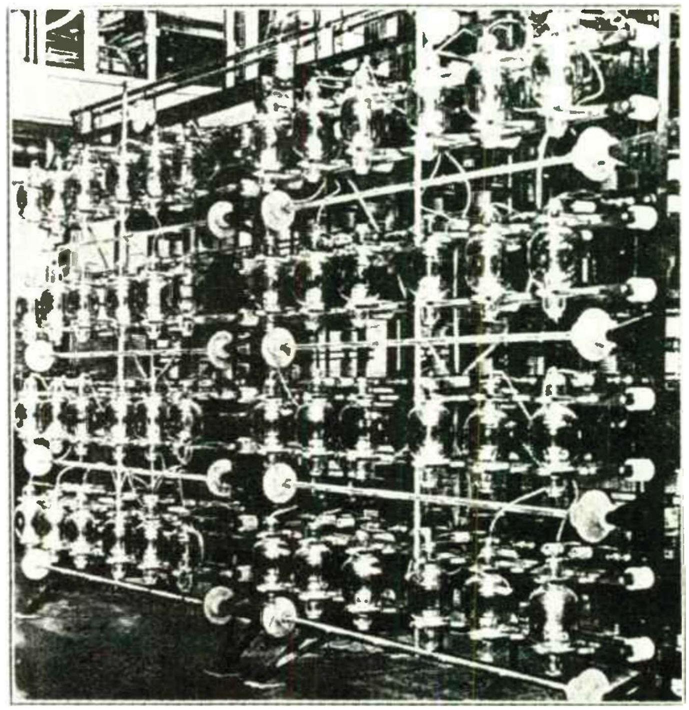

Fig. 1—Tube panel at Carnarvon

In transmission work a large amount of investigation has been carried out during the last two years on the efficiency of the circuits and in regard to the best way of utilizing the available energy.

Considerable increases in efficiency have been obtained in the aerial or antenna circuits and also in minimizing the losses in the attendant loading coils, and the latest results indicate that it is possible to obtain efficiency of radiation into space as high as 50 per cent on wavelengths as long as 20,000 meters, when, in this particular case, towers of a height of 250 meters would, of course, have to be used, owing to the length of the wave.

Very careful investigations have been carried out by Mr. H. W. Round, of all the losses in the loading coils and other parts of the tube circuits, and actual measurements on considerable power have shown that an overall efficiency from the input power on the plates of the tubes to the aerial of 70 per cent is possible with a complete avoidance of harmonics, that is, an efficiency from the power input to the plates of the tubes to actual radiation into space of about 35 per cent.

On shorter wave stations it is quite practicable still further to increase this efficiency, although possibly it is hardly worth the extra expense involved. We have at present one station in England working on a 3000-meter wavelength with a height of mast of 100 meters which

has an efficiency from plates to radiation into space of 40 per cent.

Aside from the question of efficiency, great attention has been paid to maintaining an extremely constant frequency, and this can now be guaranteed to an extraordinary degree of constancy. Simple and reliable methods of high speed keying have been developed which on the shorter waves can be used up to over 200 words per minute, and on the longer waves to whatever speed the aerial constants will permit.

In high speed transmission, we are maintaining public services at 100 words per minute to two places in Europe, namely, Paris and Berne, using a single aerial transmitter with 2 wavelengths on the same aerial, and although the operation of utilizing a single aerial for 2 wavelengths is not an advisable one for high power work, it has certain points to recommend it in medium power work, where the consequent loss of efficiency can be made up for by a slight increase of power.

These 2 waves are working duplex to both Paris and Berne and practically all traffic is taken on printing machinery, although there are occasions when, because of static, reception has to be done on undulator tape, and in some rare cases, on the telephones, by sound.

The reception at these shorter distance stations is carried out by means of a cascade arrangement of high- and low-frequency tuned amplifier circuits attached to the directional aerial system of the Bellini type, arranged for unidirectional reception when necessary. Very great care is taken in the receiving circuits to shield them so that the tuned circuits come well into action and to prevent any direct effect or influence of the aerial on circuits other than those intended to be acted upon. The characteristics of all these circuits have been very accurately measured so as to give filter curves suitable to the required speeds of working, and the adjustments are easily performed by the operators. Aside from the protection from interference given by directional reception, a close filtering, and an element of saturation, no particularly sensational methods or ideas in regard to static elimination have been so far introduced into practice.

The careful measurement and study of the constants of all circuits in use and the design of more efficient circuits from the result of those measurements is being systematically carried out, but as a result of these investigations considerable improvements have suggested themselves, which will be applied in the future if certain appropriate means can be devised.

The protection of receivers against the troubles of atmospherics or static can only be, and is likely to continue to be, a relative matter, as it is quite obvious that a static eliminator under certain conditions will cease to be effective, where the static arrives with much greater intensity than had been anticipated, and will also frequently fail when, in consequence of the weakness of the received signals, amplification has to be increased to any considerable extent.

It would be really interesting to know how much the increase in CW transmitters, the development in directional reception, and the improvements in tuning that have taken place during the last few years have really increased our speed of readability and reliability over given distances.

As the development has been gradual, the tendency is towards pessimism, but I think we are now able at the same expense to work at about 8 to 10 times the effective speed that we were able to work at in 1912 under the same atmospheric conditions.

Interference from other stations has, of course, enormously increased and this has perhaps somewhat checked the increase of speed, but fortunately prevention of interference from other radio stations is a very much easier problem than the prevention of the disturbances caused by natural electric waves, or static.

Amongst the different types of tube amplifiers used in modern radio receiving stations, the tuned high-frequency and audio-frequency amplifier is probably the one which excites the greatest technical interest. In fact, its selective qualities, combined with the comparatively better ratio of signal strength to interference which it secures, justifies such interest.

These advantages were fully realized by most radio workers during the war, and I do not think that at the time the Armistice was signed there remained many radio laboratories where some time had not been utilized in experimenting on that type of receiver.

If those researches were generally not quite successful in regard to preparing or fixing the design of practical apparatus, they however indicated that the main difficulty to be overcome was to combine considerable amplification with stability and that the solution of the problem became rapidly more difficult with the increase of the number of tubes used in cascade.

By stability, in this case, I mean the freedom from any sudden generation of oscillations in any part of the circuits of the amplifier.

In 1920, however, an important step was made by Mr. G. Mathieu, as to the path to be followed out in order to obtain a practical solution of the problem. This consisted in the design of a new type of air-core tuned intervalve transformer arranged in such a manner as to possess only an extremely small electrostatic capacity between the windings, and having its effective primary impedance about equal to the effective internal plate to filament resistance of the tube in use when the secondary circuit was brought into resonance with the frequency of the oscillations to be amplified.

The results achieved during the first tests of these new transformers appeared to be quite amazing, the amplification factor for one tube having passed suddenly from 5 to about 15 for the particular tube tested, whilst the stability proved incomparably better than what had been obtained previously, even when the grid of the tube was kept to a negative potential of 1 or 2 volts.

The same principle has proved quite as successful when applied to the design of iron-core low-frequency

transformers. In this case, however, it was found necessary to adopt an iron magnetic shunt between the windings so as to provide a sufficiently loose coupling between the primary and secondary circuits of the transformer. Recently, Mr. Mathieu has further improved the design of his high-frequency transformer by making it astatic.

One of these new appliances including high-frequency and low-frequency tuned transformers has been used daily on my yacht during my trip from England to America and the results of the tests carried out on board fully confirm the reliability of the apparatus and its marked superiority over the ordinary type of amplifier.

It has been clearly realized by most radio workers for some years that the science of radiotelegraphy had reached a stage of development where mere guesswork had done nearly all that could be expected from it, and that the improvement and development of commercial telegraphic services over what we once considered exceedingly long distances necessitated some very definite knowledge on the following points:

First: The strength of signals that can be relied upon with given arrangements over these distances, and

Second: The all-important question of the ratio of the strength of signals to that of the natural disturbances and interferences acting on the receiving station in various parts of the world.

First of all, suitable and reliable apparatus for the purpose of obtaining the necessary data on both these points had to be developed. This apparatus is now in systematic daily use in a good many far distant places, with the result that a vast amount of most valuable information is being collected, and is now coming to hand.

At these observation points, the signals from distant stations are measured at all times of the day and night, together with the strength of the interference of static, and also the direction or bearing from which the static appears to be coming.

The measurements are done in such a way that the power that would be required at the transmitting station to give readability is used as a measure of the static, as this is the actual thing a radio engineer requires for the proper calculation of his transmitting station.

It is a method which gives a very satisfactory and reliable result in practice, and which I think could well be used universally.

In short, this method consists in inducing in the aerial CW signals from the measuring apparatus, which signals are made equal to those received from the distant transmitting station. The voltage applied to the aerial can then be directly read off. An aerial of a standard size is used for the purpose, and from this the strength of the signals in microvolts per meter can be calculated. If the signals are then unreadable, due to static, the measuring apparatus is used to send to an operator at a standard rate of 20 words per minute, 5-letter code, and the voltage applied to the aerial from the local sender is increased until complete readability is obtained, thus the ratio of the new voltage applied to the aerial to that of the old voltage equal to that of the signals received gives at once a very correct estimate of how much the power of the transmitting station would have to be increased in order to insure readability. As this variation can be carried out on aerial systems giving direction diagrams the method is obviously of great practical utility.

The question as to whether it would or would not be possible to transmit radio signals right round the world as far as the Antipodes is one which has always fascinated me. In fact the distance to the Antipodes is the greatest possible useful distance that can be covered by radio on this little earth of ours, and from this point of view the question was also important as such a distance included all minor distances between all other places on earth.

Sixteen years ago at a lecture I delivered on the 3rd of March, 1905, before the Royal Institution in London I expressed the belief that if it were proved that transmission to the Antipodes were possible, the waves ought to go over and travel round different parts of the globe from one station to the other, and perhaps all converge and concentrate at the Antipodes, and in this way I thought it might be possible to send messages to such distant places by utilizing only a moderate amount of electrical energy; and at that lecture I also showed a model globe and tried to explain how I thought the waves would help each other if arriving in proper phase, or in other words, concentrate at places at or near the Antipodes of the sending station.

The results recently obtained and which go to show the relative facility with which radio signals can now be sent from England to Austrialia seems to indicate that there is something in the idea of the wireless waves traveling round the earth by various ways and reuniting at places near the Antipodes.

But still more interesting and precise data has been obtained during other more recent tests.

Two expeditions, one to Brazil, and the other to New Zealand, have carried out a number of most interesting and instructive observations, and although complete reports have not yet been received, I think it will nevertheless be of interest if I give you the results of some of their important tests.

The expedition to Brazil of which Mr. H. H. Beverage, of the Radio Corporation of America, Mr. N. W. Rust, of Marconi's Wireless Telegraph Company of England, and Mr. W. Eichkoff and Dr. A. Esau of the Gesellschaft für Drahtlose Telegraphie (Telefunken) of Berlin formed part, has just completed a series of observations at various points on the Atlantic Coast of South America, where the intensity of the signals from European and other stations has been observed and measured at all times of the day and night, and where also the direction and intensity of atmospherics or static has been equally observed and recorded over considerable periods of time.

Another expedition under the direction of Mr. E. Tremellen, of the English Marconi Company, has just completed its work in measuring signals from all European and American high power stations, on a journey between England and New Zealand via the Panama Canal, and from the mass of information obtained on both day and night signals it should be possible, among other things, to reconstruct the attenuation formula. Incidentally, I may say that the signals exceed greatly in strength what should be expected according to the Austin-Cohen formula, otherwise super-long-distance working would not be a practical proposition.

Complete measurements from England to the Antipodes have been made on the Carnarvon, Nauen, Bordeaux, and Hanover signals; and also in Brazil on the American high power stations and on the U. S. Naval station, N.P.O. at Cavite (Philippine Islands).

In both these expeditions to Brazil and New Zealand the fact has been noted definitely and independently, and I think for the first time, that signals from stations at very great distances do not always retain their direction along one great circle, but reach the receiver from either way or various ways round the earth.

These important observations were made by means of loop aerial direction finders arranged so as to give the well-known heart-shape diagram and the very interesting fact has been recorded independently by both expeditions, that on many occasions during what might be called a transition period, when the wave is changing from one way round the earth to another way round, the two or more sets of waves when received on a simple vertical aerial produced fairly slow beats resembling Morse signals, caused by the mutual interference or addition of the two sets of waves, whereas on the direction-finder heart-shape diagram arrangement, the signals were quite steady and normal when it was turned so as to receive only from one way or the other.

Of course it should be noted that when one is very near to the Antipodes there is only such a slight difference between any of the great circles leading from the sending station that the constancy of direction is not maintained, but this direction seemed to keep definitely true at distances of about 2000 miles from the Antipodes.

The observers noted American signals from Radio Central and from Tuckerton coming from a direction which indicated that they preferred to travel a distance of three quarters of the way round the earth, rather than come by the shortest way round. Also, according to the reports received from the observers on other occasions at or near the Antipodes of the English or German stations, the direction finder often indicated the signals as coming from directions all round.

Another interesting and rather extraordinary result was noted on several occasions, according to the report of Mr. Tremellen from Rocky Point, New Zealand, where during last March the signals from Nauen appeared to travel to him via the South Pole, whilst those from Hanover, also situated in Germany, and not very far from Nauen, appeared to prefer to travel via the North Pole.

A much more complete and exhaustive series of observations at fixed stations in Australia is now being made so as to obtain if possible all the variations from one period of the year to the other.

It seems to have been definitely ascertained in a general way that the sources of bad atmospheric disturbances, or static, are situated chiefly over land, but observations in Brazil indicate that a type of static known as "grinder" is a disturbance originating a long way off and coming from a direction which indicates the African Coast and at a time of the day when static there would be at a maximum, whereas a very violent "click" type of static came from a direction indicating its source as being nearby in South America.

During my present journey across the Atlantic, on board the Yacht *Elettra*, we noticed that up to about halfway across (apart from the effects of local storms) static interference appeared to be coming mainly from the European and African continents, while at more than halfway across they were coming from Westerly directions, that is, from the American continent.

The changing over of the direction of origin of these disturbances has also been noted under similar circumstances by Mr. Tremellen in crossing the Pacific.

It is very fortunate for the North Atlantic transatlantic radio service, carried out at stations in North America and Europe, particularly for those in Western Europe, that this strong nearby type of static comes from directions which greatly differ from those from which one has to receive, and that the continents which lie in the direction of the sending stations are so far distant and sufficiently temperate as not to project troublesome static to the receiving stations on the other side of the ocean.

Another fact which can be fairly well deduced from these tests over very great distances is that transmission from West to East is apparently easier than from East to West, and shows the necessity for qualifying or modifying the transmission formula for great distances.

A scientific paper giving the results of measurements and of all the work carried out and observations made in these two expeditions will shortly be published.

I shall now deal with another and most important branch of the science of radiotelegraphy; a branch which I might say has been for a long time most sadly neglected. It concerns the use that can be made of very short waves, especially in regard to their application to directional radiotelegraphy and radiotelephony.

Some years ago, during the war, I could not help feeling that we had perhaps got rather into a rut by confining practically all our researches and tests to what I may term long waves, or waves of some thousands of feet in length, especially as I remembered that during my very early experiments, as far back as 1895 and 1896, I had obtained some promising results with waves not more than a few inches long.

The study of short waves dates from the time of the

discovery of electric waves themselves, that is, from the time of the classical experiments of Hertz and his contemporaries, for Hertz used short electric waves in all his experiments, and also made use of reflectors to prove their characteristics and to show among many other things that the waves, which he had discovered, obeyed the ordinary optical laws of reflection.

As I have already stated, short electric waves were also the first with which I experimented in the very early stages of wireless history, and I might perhaps recall the fact that when, over twenty-six years ago, I first went to England, I was able to show to the late Sir William Preece, then Engineer in Chief of the British Post Office, the transmission and reception of intelligible signals over a distance of $1\frac{3}{4}$ miles by means of short waves and reflectors (Figs. 2 and 3), whilst, curiously enough, by means of the antenna or elevated wire system, I could only get, at that time, signals over a distance of half a mile.

The progress made with the long-wave or antenna system was so rapid, so comparatively easy, and so spectacular, that it distracted practically all attention and research from the short waves, and this I think was regrettable, for there are very many problems that can be solved, and numerous most useful results to be obtained by, and only by, the use of the short-wave system.

Sir William Preece described my early tests at a meeting of the British Association for the Advancement of Science, in September, 1896, and also at a lecture he delivered before the Royal Institution in London on the 4th of June, 1897.

On the 3rd of March, 1899, I went into the matter more fully in a paper I read before the Institution of Electrical Engineers in London, to which paper I would recall your attention as being of some historical interest.

At that lecture I showed how it was possible, by means of short waves and reflectors, to project the rays in a beam in one direction only, instead of allowing them to spread all around, in such a way that they could not affect any receiver which happened to be out of the angle of propagation of the beam.

I also described tests carried out in transmitting a beam of reflected waves across country over Salisbury Plain in England, and pointed out the possible utility of such a system if applied to lighthouses and lightships, so as to enable vessels in foggy weather to locate dangerous points around the coasts.

I also showed results obtained by a reflected beam of waves projected across the lecture room, and how a receiver could be actuated and a bell rung only when the aperture of the sending reflector was directed towards the receiver.

Since these early tests of over twenty years ago practically no research work was carried out or published in regard to short waves, so far as I can ascertain, for a very long period of years.

Research along these lines did not appear easy or promising; the use of reflectors of reasonable dimensions

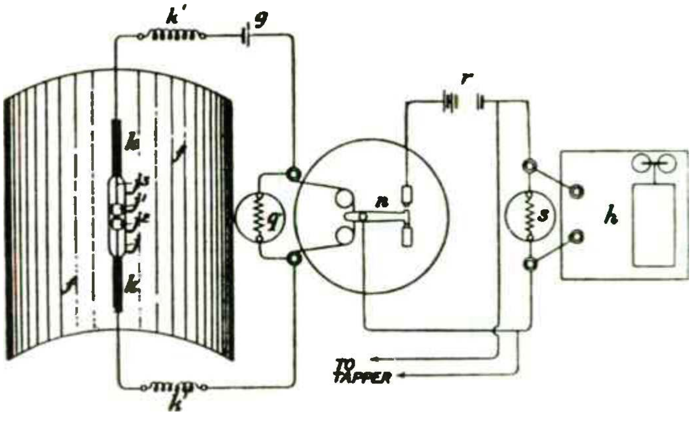

Fig. 2—Early short-wave directional receiver.

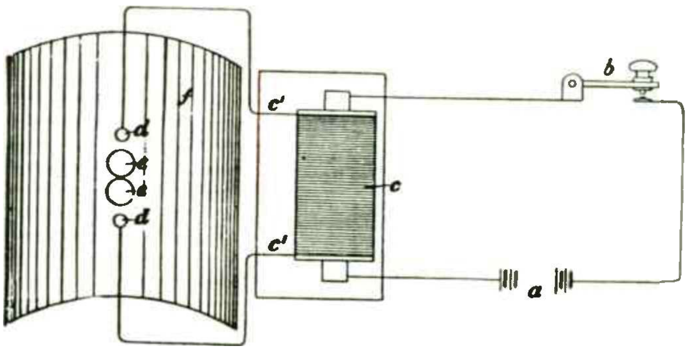

Fig. 3—Early short-wave directional transmitter.

implied the use of waves of only a few meters in length, which were difficult to produce, and, up to a comparatively recent date, the power that could be utilized by them was small. This and the fact of the very high attenuation of such waves, over any distance of land or sea, gave results which appeared to be very disappointing.

The investigation of the subject was again taken up by me in Italy early in 1916 with the idea of utilizing very short waves combined with reflectors for certain war purposes, and at subsequent tests during that year, and afterwards, I was most valuably assisted by Mr. C. S. Franklin, of the British Marconi Company.

Mr. Franklin has since then followed up the subject with great thoroughness and the results obtained have been described by him in a paper read before the Institution of Electrical Engineers in London on the 3rd of April, 1922.

Most of the facts and results which I propose to bring to your notice are taken from Mr. Franklin's paper.

The work carried out in experimenting with these waves in 1916 was most interesting, as it was like going back to the early days of wireless, when one had a perfectly clear field.

The waves used had a length of 2 meters and 3 meters. With these waves, disturbances caused by static can be said to be almost nonexistent, and the only interference experienced came from the ignition apparatus of automobiles and motor boats. These machines apparently emit electric waves from near 0 to about 40 meters in

length, and the day may come when they will perhaps have to have their ignition systems screened, or carry a Government license for transmitting.

Incidentally I might mention that one of these short-wave receivers will act as an excellent device for testing, even from a distance, whether or not one's ignition is working all right. Some motorists would have a shock if they realized how often their magnetos and sparking plugs are working in a deplorably irregular manner.

During my tests in 1916, I used a coupled spark transmitter, the primary having an air condenser and spark in compressed air. By these means the amount of energy was increased and the small spark gap in compressed air appeared to have a very low resistance.

The receiver at first used was a crystal receiver, whilst the reflectors employed were made of a number of strips or wires tuned to the wave used, arranged on a cylindrical parabolic curve with the aerial in the local line.

The transmitting reflector was arranged so that it could be revolved and the effects studied at a distance on the receiver.

Mr. Franklin has calculated the polar curve of radiation into space (Fig. 4), in the horizontal plane, which should be obtained from reflectors of various apertures, by assuming that the waves leave the reflector as plane waves of uniform intensity, having a width equal to the aperture of the reflector. The calculated curves agree very well with the observed results. In Fig. 4 are shown the calculated curves for reflectors having apertures equal to 1, 2, 3, and 5 wavelengths.

Reflectors with apertures up to $3\frac{1}{2}$ wavelengths were tested, and the measured polar curves agreed very well indeed with the calculated values.

The Italian experiments showed that good directional working could always be obtained with reflectors properly proportioned in respect to the wavelength employed, and with the apparatus then available the range obtained was 6 miles.

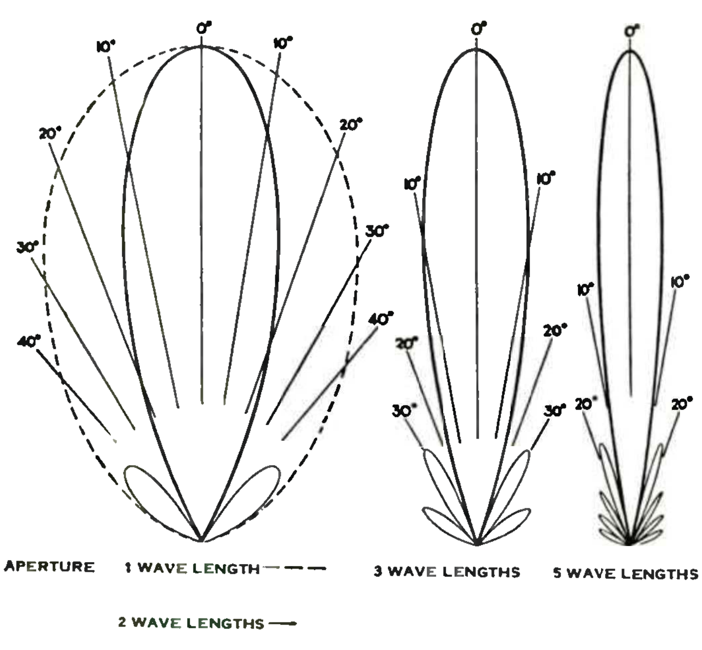

Fig. 4—Calculated polar curves of reflectors.

The tests were continued in England at Carnarvon during 1917. With an improved compressed air spark gap transmitter, a 3-meter wave, and a reflector having an aperture of 2 wavelengths and a height of 1.5 wavelengths, a range of over 20 miles was readily obtained with a receiver used without a reflector.

In 1919 further experiments were commenced by Mr. Franklin at Carnarvon for which electron tubes or valves were used to generate these very short waves, the object being to evolve a directional radiotelephonic system.

A 15-meter wave was chosen, which could quite easily be generated by the type of electron tube employed.

After overcoming a few practical difficulties, very strong and clear speech was received in Holyhead 20 miles away. Longer distance tests were next undertaken and a receiving set of apparatus was installed on one of the mail boats running between England and Ireland.

During these tests clear speech was received all the way over to the Irish coast and into Kingstown Harbour at a distance of 78 miles from Carnarvon. The important fact was also noticed that there was no rapid diminution of the strength of signals after the ship had passed the horizon line from Carnarvon.

As a result of the success of these experiments it was decided to carry out further tests over land across a distance of 97 miles between Hendon (London) and Birmingham.

It was proved at once that, with reflectors at both ends, good and clear speech could be exchanged at all times between the two places.

The following are some particulars of the arrangements employed at Hendon and at Birmingham (Figs. 5 and 6).

The power supplied to the tubes employed is usually 700 watts. The aerial is rather longer than half a wavelength and has a radiation resistance which is exceedingly high. The efficiency input to the tubes to aerial power is between 50 and 60 per cent, and about 300 watts are actually radiated into space.

With the reflectors in use at both ends speech is strong and of very good quality. It is usually strong enough to be just audible with a $\frac{1}{4}$- to $\frac{1}{2}$-ohm shunt across a 60-ohm telephone.

With both reflectors down and out of use, speech is only just audible with no shunt. Average measurements made by Mr. Franklin indicate that the value of the energy received when both reflectors are used is about 200 times that of the energy received without any reflectors.

These figures have been lately confirmed by local measurements taken round the stations.

Fig. 7 shows a measured polar curve of the field of Hendon station taken in the vicinity of the reflector. It is rather unsymmetrical in consequence perhaps of the ground being on a slope, and owing to local reflection from trees and wires.

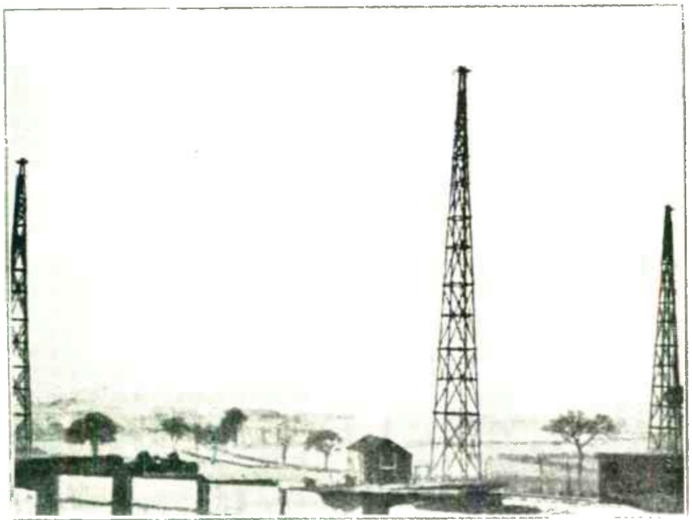

Fig. 5—Directional transmitter (Hendon).

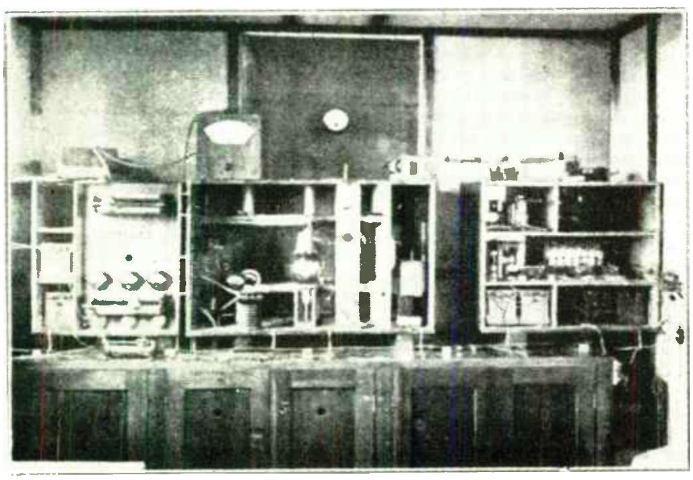

Fig. 6—Experimental short-wave transmitter and receiver at Hendon.

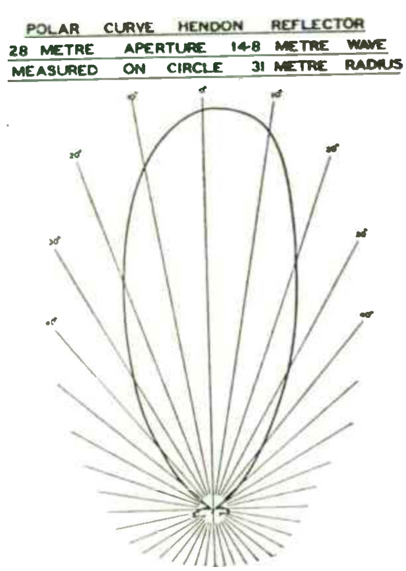

Fig. 7—Polar curve of Hendon reflector.

It has occurred to some of my assistants that a polar curve taken locally round the station may not be the same as a curve taken at a distance, and that at a distance the directional effect may be lost. I am, however, in agreement with Mr. Franklin that such is not the case.

Experiments carried out with revolving reflectors, which make it easy to read measurements at any distance, prove that the polar diagram for a given reflector and wavelength is practically constant at all ranges.

By means of suitable electron tubes or valves, it is now quite practicable to produce waves from about 12 meters and upwards utilizing a power of several kilowatts, and it is also practicable to utilize valves in parallel.

During the CW tests at Carnarvon, it was found that reception was quite possible on the transmitting aerial whilst the transmitter was operating.

This system is being used successfully for duplexing between Hendon and Birmingham, as it avoids all switching.

Reflectors besides giving directional working, and economizing power, are showing another unexpected advantage, which is probably common to all sharply directional systems. It has been noted that practically no distortion of speech takes place, such as is often noticed with nondirectional transmitters and receivers, even when using short waves.

The results between Hendon and Birmingham easily constitute a record for radiotelephony in respect to the ratio of distance to wavelength, as Birmingham, it may be interesting to note, is 10,400 wavelengths from Hendon.

We consider, however, that these results represent only what could be obtained from a first attempt, and not what could now be done after the experience gained.

It has thus been shown for the first time that electric waves of the order of 15 to 20 meters in length are quite capable of providing a good and reliable point-to-point directional service over quite considerable ranges.

In these days of broadcasting, it may still be very useful to have a practically new system which will be to a very large degree secret, when compared to the usual kind of radio.

The results obtained by reflectors appeared to be so good that I was tempted to try out my old idea of twenty-six years ago, and test the system as a position finder for ships near dangerous points. This is now being done in Scotland through the courtesy of Messrs. D. and C. Stevenson and of the Commissioners of Northern Lights. Trials are being carried out under the supervision of Mr. Franklin with a revolving reflector erected at Inchkeith Island in the Firth of Forth near Edinburgh. The transmitter and reflector, revolving, act as a kind of wireless lighthouse or beacon, and, by means of the revolving beam of electrical radiation, it is possible for ships, when within a certain distance, to ascertain in thick weather the bearing and position of the lighthouse.

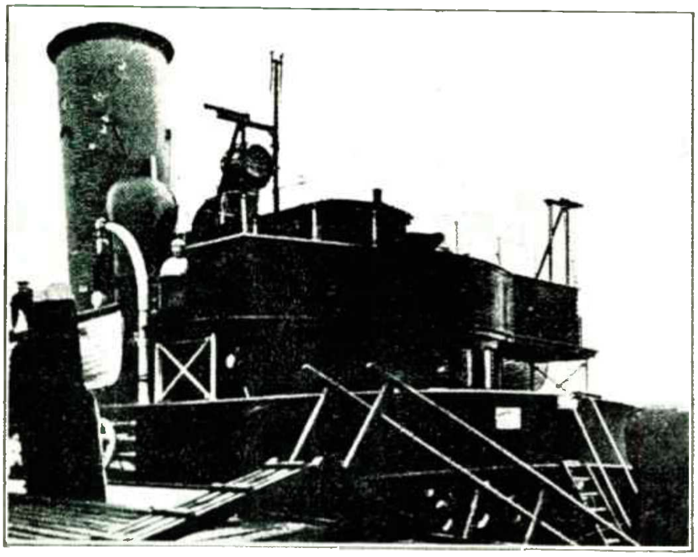

Fig. 8—Short-wave receiver on Steamship *Pharos.*

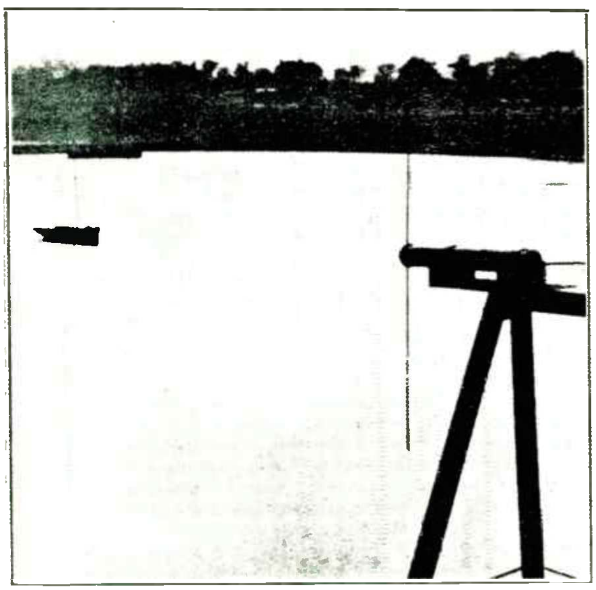

Fig. 9—Short-wave receiver.

The experimental revolving reflector was erected and the first tests were carried out with the S. S. *Pharos* during the autumn of 1920 (Fig. 8).

With a 4-meter wave spark transmitter, a reflector, and a single tube receiver, suitably tuned, on the ship, a working range of 7 miles was obtained.

The reflector was caused to make a complete revolution every two minutes, and a distinctive signal was sent every half-point of the compass. It was ascertained on the steamer that this enabled the bearing of the transmitter to be accurately determined within a quarter-point of the compass, or within 2.8 degrees. At a later date a new reflector was designed and erected and is now being tested (Fig. 12).

Fig. 10 shows measured polar curves taken recently with the new reflector. The curves were measured at a distance of 4 miles.

With the revolving beam the exact times of maximum signals are not easy to judge, by ear, but the times of

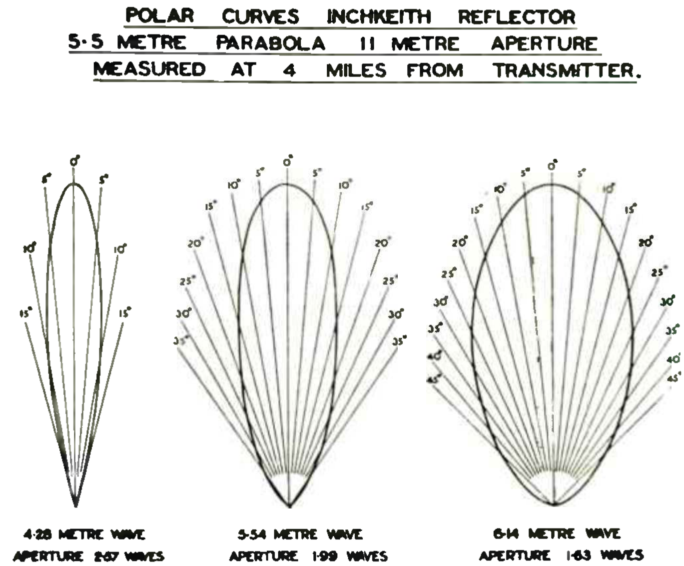

Fig. 10—Polar curves of Inchkeith reflector.

starting and vanishing are easy to determine, as the rate of rise and fall of the signals is extremely rapid. The time halfway between these two times gives, with great exactness, the moment when the beam is pointing to the ship (Fig. 11).

By means of a clockwork arrangement a distinctive letter is sent out every two points, and short signs mark intermediate points and half-points; and this is done in practice by contact segments arranged on the base of the revolving reflector, so that a definite and distinctive signal is transmitted at every half- or quarter-point of the compass (Fig. 12).

I will now try to show you the working of a roughly constructed 1-meter wave transmitter and reflector.[1]

The attenuation of these short waves over sea is so surprisingly regular that a little experience enables distance to be judged by the strength of signals, and this can be measured by means of a potentiometer.

Before I conclude I should like to refer to another possible application of these waves which, if successful, would be of great value to navigators.

As was first shown by Hertz, electric waves can be completely reflected by conducting bodies. In some of my tests I have noticed the effects of reflection and deflection of these waves by metallic objects miles away.

It seems to me that it should be possible to design apparatus by means of which a ship could radiate or project a divergent beam of these rays in any desired direction, which rays, if coming across a metallic object, such as another steamer or ship, would be reflected back to a receiver screened from the local transmitter on the sending ship, and thereby immediately reveal the presence and bearing of the other ship in fog or thick weather.

[1] At this point, Senatore Marconi demonstrated the transmission of 1-meter continuous waves from a parabolic reflector of the type shown in Fig. 3, and composed of parallel wires, over a distance of approximately 15 meters to a tube receiver with reflector similar to that of Fig. 2. Absorption of the waves by a tuned resonator was also shown—EDITOR.

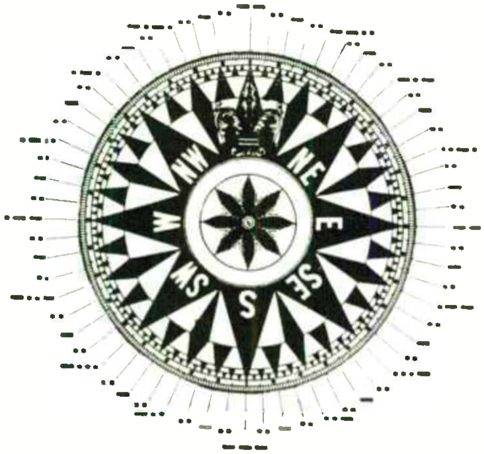

Fig. 11—Compass bearings with letter designations for radio direction finding.

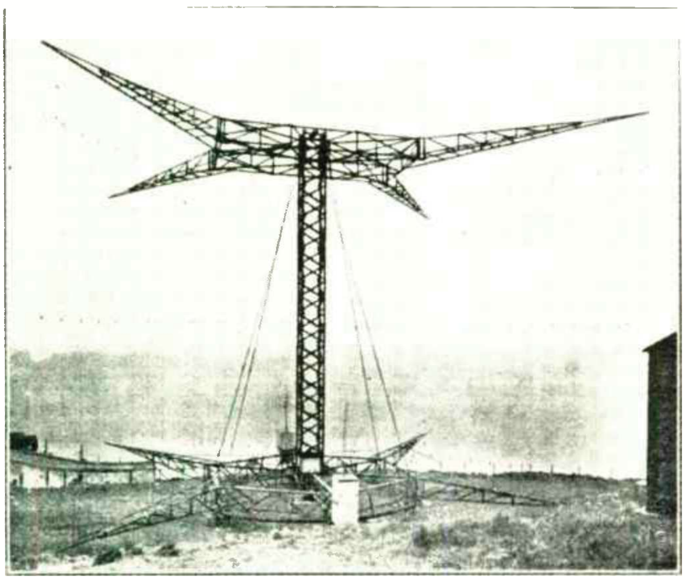

Fig. 12—Rotating short-wave directional transmitter, Inchkeith.

One further great advantage of such an arrangement would be that it would be able to give warning of the presence and bearing of ships, even should these ships be unprovided with any kind of radio.

I have brought these results and ideas to your notice as I feel—and perhaps you will agree with me—that the study of short electric waves, although sadly neglected practically all through the history of wireless, is still likely to develop in many unexpected directions, and open up new fields of profitable research.

Having referred so lengthily to what is essentially a directional system, that is, a system that does not spread its waves all round, you will perhaps expect a few words from me before I bring this rather lengthy discourse to a close, on the subject of "Broadcasting."

No remarks from me or from anyone else are required to tell you what has already been done with radio in America, as a means of broadcasting human speech, and other kinds of sound which may also be entertaining if not always instructive.

In thousands of homes in this country there are radiotelephonic receivers, and intelligent people, young and old, well able to use them—often able to make them and in many instances contributing valuable information to the general body of knowledge concerning the problems great and small of radiotelegraphy and radiotelephony.

But I think I am safe in saying that if radio has already done so much for the safety of life at sea, for commerce, and for commercial and military communications it is also destined to bring new and, until recently, unforeseen opportunities for healthy recreation and instruction into the lives of millions of human beings.

Abstract

The lecture first deals briefly with the early history of long distance radio communication.

The work carried out by the engineers and experts of the Marconi Company in England with electron tubes or triode valves shows that, according to their experience, greater efficiency can be obtained at present by a number of bulbs used in parallel than by the employment of large single unit tubes.

Information is given in a general way in regard to recent practice in the design and construction of receivers with the object especially of improving selectivity, reducing interference, and concerning the possible speed of working.

The lecture also deals briefly with results obtained at receiving observation stations situated in various far distant parts of the world, where it has been ascertained that radio signals arriving from high power stations situated at or near the antipodes of the observation stations, reach the receivers by various ways around the earth, not always following the shortest great circle route, and also that at such places the electric waves coming round by different ways do in certain cases increase this effect on the receivers whilst in others interfere with each other.

It has also been noticed that apparently transmission is easier from west to east than from east to west, and that it may be necessary to modify somewhat the transmission formula for long distances.

It has also been ascertained that the most troublesome atmospheric disturbances or static usually come from the continents and not from the oceans.

The lecture further deals with a study of short electrical waves and the results which have been obtained with such waves of a length from 1 meter to 20 meters, and describes tests which show for the first time that electric waves of under 20 meters in length, used in connection with suitable reflectors, are quite capable of providing a good and reliable point-to-point, unidirectional system of radio over quite considerable distances.

The application of this system as a direction finder in aid of navigation, and as a method for preventing collisions at sea, is also dealt with.